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AUTHOR Graves, George R.
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ABSTRACT

This study applies the methodology of systems dynamics to analyze engineering and engineering technology education systems. A preliminary system analysis is presented relating primary variables and their interaction in the overall system through a series of feedback loops. This is followed by a system structure development and mathematical modeling leading to a computer simulation of the system. (Author/RE)

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SYSTEM DYNAMICS
APPLIED TO
TECHNICAL EDUCATION PLANNING

by

George R. Graves
Professor and Chairman Aerospace Engineering Dept.

California State Polytechnic University, Pomona
Pomona, California

July, 1975

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SUMMARY

Factors affecting higher education and engineering education are social, economic, political, ecological and technological in nature and are necessary inputs to any systemized planning based on future needs.

Forecasting methodologies are presented and evaluated. The preference for this study, a methodology designated as System Dynamics, is utilized to perform a system analysis of engineering and engineering technology education.

Initially, the methodology is used to perform a preliminary system analysis relating the primary variables and their interactions in the overall system through a series of feedback loops.

The preliminary system analysis is generally followed by a system structure development and mathematical modeling leading to a computer simulation model of the system.

Due to limitations in funding this study was restricted to the development of system structures and computer simulation models for the following sub-systems:

- University Technical Enrollment
- University Technical Manpower Resources

INTRODUCTION

INTRODUCTION

"The past three decades have been witness to major transformations in educational environments and themes of universities and colleges in the United States. The relatively cloistered academic atmosphere of the pre war era was radically transformed by successive waves of change after World War II. The G. I. Bill of Rights opened the doors to academe to thousands who never would have crossed the thresholds without it."[1] As the number of these beneficiaries increased and matured in age, the appreication of the value of higher education led to a large proportional increase in the population seeking a university education. The burgeoning birth rates of the late 40's and early 50's resulted in increased demands on educational institutions in the 60's that taxed not only available facilities and faculty, but also the search for relevancy in educational taxonomy.

If the initial years are indicative, the decade of the 70's will witness a reversal of past trends. The post World War II baby boom is over. Social attitudes, birth control measures and the legalization of abortion are reflected in the continuing decline in birth rate. The consequent receding of primary school enrollments forecasts a decline in secondary schools, community colleges and universities in the later part of the decade. There are indications that many prospective students are turned off by high college costs and no longer believe that a degree will automatically increase their economic status. They see evidence in newspaper accounts and elsewhere of teachers, engineers and other white collar career occupations, once considered quite stable, being racked by low or no demand and reductions in force.

[1]Centner, S. I., System Analysis and Higher Education Planning, (Ref. 1, Pg. 139).

Career education or job skill occupational programs if not being self initiated by present high school graduates will be appearing on the scene in the next few years. This program is strongly supported by the U.S. Office of Education under the direction of Commissioner Sidney Marland, Jr., its principal advocate. Career education emphasizes the vocational aspects of the substantive content that is being taught in the classroom and utilizes occupationally oriented experiences as a teaching and motivating device. In career education, provisions are made for "equivalency substitution" of job skills to fulfill the course requirements of such academic areas as English, Mathematics, etc. The philosophy of career education is, in general, finding wide acceptance among boards of education for implementation at both grade and high school levels. As this program evolves, universities and colleges will be petitioned to relax admission standards from those based on traditional academic programs. From all indications, a strong--well developed career education program will direct increasing numbers of high school graduates with earning power skills into the open job market thereby further diverting the higher education enrollment.

> "*Today, in higher education circles* the dialogue is: continuing education, external degrees, extended universities, universities without walls, etc. These phrases seek to describe the radical increase in the options through which individuals can pursue learning and obtain formal recognition for what they have learned."[2]

Programs such as these have experienced diverse reactions from faculty in the past and there is no reason to conclude that as their scope broadens the intensity of debate will diminish. Traditionally, evaluation of

[2]Kimmel, E. W. (Ref. 7 Pg. 484-486).

competency and the awarding of credit were in the purview of the individual faculty teaching the course. Now many external degree programs are utilizing the devices of "academic equivalence" or credit by examination on standardized tests to determine credit toward degree requirements.

Significant factors of these programs as they relate to higher education are possible reductions in course enrollments and diversification of faculty to meet the widely varying needs of individuals, industry and society. To benefit from continuing education and external degree programs, universities will require administrators who understand the field and its inherent needs, its impact on the standard university program and higher education in general. Faculty will have to learn to interface with a more adult clientele. Faculty will also have to be knowledgable in advances in the fields in which they teach. Industry has been struggling to develop their own continuing education programs because institutions of higher education have been lagging behind. The competition for the continuing education scholar is one which universities must face in the immediate future if not now. If the needs of continuing education and external degree programs can be met in an optimum fashion, the effect of decreasing enrollment may be negated to some extent and higher education will reflect an added new dimension in the future.

Education and technology, two major aspects of our society have the dubious honor of sharing extensive criticisms during recent years.

> Technology is in trouble, the critics say, because it has not met the needs of society. Until recently, society assumed that technology would provide the means to improve our standard of living even thought we were reaching deeper into our store of

> raw materials and energy resources. Now the nation has realized that the plan has gone awry. Little by little the edges of society are beginning to crumble. Technology--in which so much faith and hope had been placed--hasn't been producing any where near the payoff the public has been led to expect from it.[3]

Education in many respects is traveling an analogous path. Both in technology and education the 60's were the golden years. For a decade there had been remarkable and seemingly unlimited growth. Financial support seemed solid. Teachers, engineers, professors and scientists were acknowledged creditable professionals. The attitude toward higher education began to turn in the middle 60's with the appearance of the free speech movement and was carried forward with demonstrations against the Vietnam War. Public reaction to the radical departure from accepted social norms triggered reactive political restraints on the funding and functioning of institutions of higher learning by federal and state legislative bodies. The demonstrations and movements of the 60's have now appeared to move into history. Such does not appear to be the case of public attitude with respect to the cost of higher education and its drain on the tax dollar. Tuition is under consideration in many states that once proclaimed the right of all to free higher education. The large growth rate of faculties, proliferation of new programs and capital outlay improvements are being replaced by resource allocation, cost benefit and faculty activity analyses. "Accountability" may well be a modus operandi of higher education in the near future. It has been implemented in primary and secondary education circles to some extent already.

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[3]Khol, R. (Ref. 8, Pg. 98).

The economic prognosis for the forthcoming decade is promising even though present trends in technology funding are of some concern. Since the gross national product provides a comprehensive measure of the aggregate economic performance and well being of the nation, its projected trajectory becomes a significant variable in estimating the expenditures for technological effort. Actual and projected figures for the GNP indicate a steady upward trend for the period 1968 to 1980 as indicated.

Gross National Product
(In Billions of Dollars)

1968	1971	1972	1973	1975	1980
$ 865	$1050	$1151	$1264	$1429	$2000

The technological economic pattern since 1967 does little to establish credence in the overall economic growth projections.

> "There is expressed concern that the United States may be heading toward second class status in the community of technological nations. A growing body of informed opinion holds that such an eventuality may take place within the decade unless drastic measures are taken to stem the deterioration of the U.S. position in the last five years."[4]

These conclusions are also confirmed by a recent study of international research and development (Ref. 12).

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[4] Glasser, O. J., *A WARNING: RUSSIA, EUROPE CATCHING UP WITH U. S. TECHNOLOGY* Los Angeles Times, August 6, 1972.

International research and development (R&D) trends and policies, in which the level of a nation's R&D, including the extent to which it is supported by the government, is considered one of the principal indicators of future technological and trade capability. In most of the nations studied, the governments are supporting vigorous R&D programs that are growing annually in funding and scope. By contrast, the growth rate of U.S. government-financed R&D is almost stagnant and the overall rate--federal plus private financing--is among the lowest of major nations.

In terms of total expenditures, U.S. research and development has expanded considerably since 1960, more than doubling from a base of $13.7 billion a year. This single fact, however, is misleading since practically all of the growth took place before 1968. Since that year, outlays have remained at about the same level, which represents a declining R&D capability because of inflation and the increasingly higher costs associated with advanced technology. Since 1966, the growth rate of government R&D funding has plummeted from 9 percent to less than one percent. Substantial annual increases in non-federal funding--mostly from industry--have not taken up the slack.

While the level of effort for R&D remains static in the U.S., substantial increases are being recorded in government support of R&D in other nations. France, for example, is experiencing an annual growth rate of about 13 percent; Japan's growth runs to almost 25 percent and in the Federal Republic of Germany it is 30 to 40 percent. A further influence on future trade is the fact that these and other nations are concentrating the greater portion of their R&D resources in economically-motivated effort,

while the U.S. has, of necessity, maintained a broad spectrum with emphasis on defense, nuclear and space research. U.S. funding in these areas has dropped off sharply in recent year, but defense-nuclear-space activity still constitutes more than half of the U.S. total research and development effort.

Productivity growth tends to parallel the level of R&D investment. From 1870 to 1950, the U.S. productivity growth rate exceeded that of Europe by 60 percent and Japan by 70 percent; since 1965, the U.S. has trailed Europe by 35 percent and Japan by 60 percent. Over the past 5 years, U.S. productivity growth has averaged about 1.7 percent annually, compared with 4.5 percent in Europe and 10.6 percent in Japan.

In international trade, the U.S. is no longer the world's largest exporter of manufactured goods; that position was ceded to West Germany in 1970. For the first time in this century, the nation faces for 1971 the distinct possibility of trade deficit. From a surplus of $5 to $7 billion in the early sixties, the balance declined to a plus-level of only $1 to $2 billion by the late sixties and the trend toward deficit continues.

Trading trends show persistent U.S. deficits--as much as $6 billion in 1971--in raw materials and low-technology manufactures. Thus far, these deficits have been more than offset by annual surpluses in high-technology products, such as aircraft, electronics and automotive products.

Even in the high-technology areas, however, disturbing trends exist. U.S. high-technology exports mounted steadily from $13 billion in 1965 to nearly $23 billion in 1970, but imports in the same category increased at a much

higher rate during the same time span, growing from about $4 billion to $13 billion, for a gain of more than 230 percent. The U.S. share of world exports of research-intensive products dropped from a level of 35 percent in 1955 to just under 30 percent a decade later, then stabilized at about that level.

Employment and Labor adds a further perspective to trends in the forthcoming decade. Since labor force projections are based on the number of individuals 16 years and older, plus assumptions about labor force participation rates, projections for up to 16 years ahead are based on numbers of people already born. The margin for error lies in the assumed participation rate, a variable dependent on institutional factors, which change relatively slowly. Thus projections of labor force to 1980 may be viewed with a reasonable degree of confidence.

Employment projections depend initially upon labor force projections and secondarily on unemployment rate assumptions. Since unemployment is cyclically variable, this projection is based on long-term experience, and what is considered to be probable. No attempt to forecast cyclical variations has been made.

The goal of full employment has been pursued somewhat more vigorously in the past decade than during the 1950's. It is expected that government policy will continue to attempt to eliminate the various sources of unemployment, and that a reasonably high rate of economic growth will facilitate these efforts. The nature of unemployment, however, will continue to change. If any major characteristic can be used as a description of the

economy in the 1970's, it is accelerating technical change. Such change implies that some workers' skills will become obsolete and demands for newer, more sophisticated skills will increase. Evidence of this trend is already apparent in severe shortages of some types of technical workers. While there are likely to be many new jobs created during the next decade, a supply of the necessary skills is not assured. Thus, the problem of unemployment will increasingly become a problem of training the unskilled, and retraining those with obsolete skills. As a corollary, the technological innovators, may experience substantial difficulty in finding adequate human inputs. On-the-job training and retraining, and expenditure by business for continuing education of employees, are therefore likely to become more and more common.

Contributions to economic growth from the advance of knowledge are expected to increase at an increasing rate. This assumption is based on the observed, roughly exponential growth of technological advance. Similarly, there appears to be no substantial evidence to suggest that economies of scale will contribute any less to growth in the future. Technical economies, considering the expectation of accelerating innovation, should provide increasing gains in many industries."[5]

With undue selectivity and weighting, the foregoing discussion has examined, in a cursory fashion, a cross section of elements that will influence higher education in the years ahead. Obviously, a multitude of factors will affect the educational system in varying degrees. However, even this limited array of variables illustrates that higher education and engineering

[5] (Ref. 11 Pgs. 5-8).

education in particular have been, are now and will in the future be subjected to the pressures and trends of economic, ecological, sociological, political and technological environments. Engineering education and technology control their own destinies only in a very limited sense; the major forces that chart the course are economic, sociological and political in nature. Technology reacts to the constraints of these forces and exerts its influence in the overall system to effect subsequent changes. This premise of reaction is supported by such overwhelming evidence that its rejection is essentially precluded. One need only recount the many faceted priority shifts proposed for technology in this decade that result from vagrant political, economic and social decisions.

If the supposition holds that engineering education and technology have only a limiting influence on this seemingly vagarious system of ours, then it is essential that a method be devised for interpreting the random elements of the process; any methodology selected will not be free from error but it should enhance to a measurable degree an awareness of the variables that determine the trajectory of the engineering profession. It would appear that this should be a prime responsibility of the educational counterpart of engineering if institutions of higher education are to play a meaningful role in the process. The prevelant short term inadequate planning theme of--"what does industry want"--must be replaced by long term planning themes that provide for the inherent delay between matriculation and graduation, and the ever shifting economic, sociological and technological trends. Thus, planning must be "needs" and "future" oriented to allow the academic process to function meaningfully in curriculum and course development to meet these future needs.

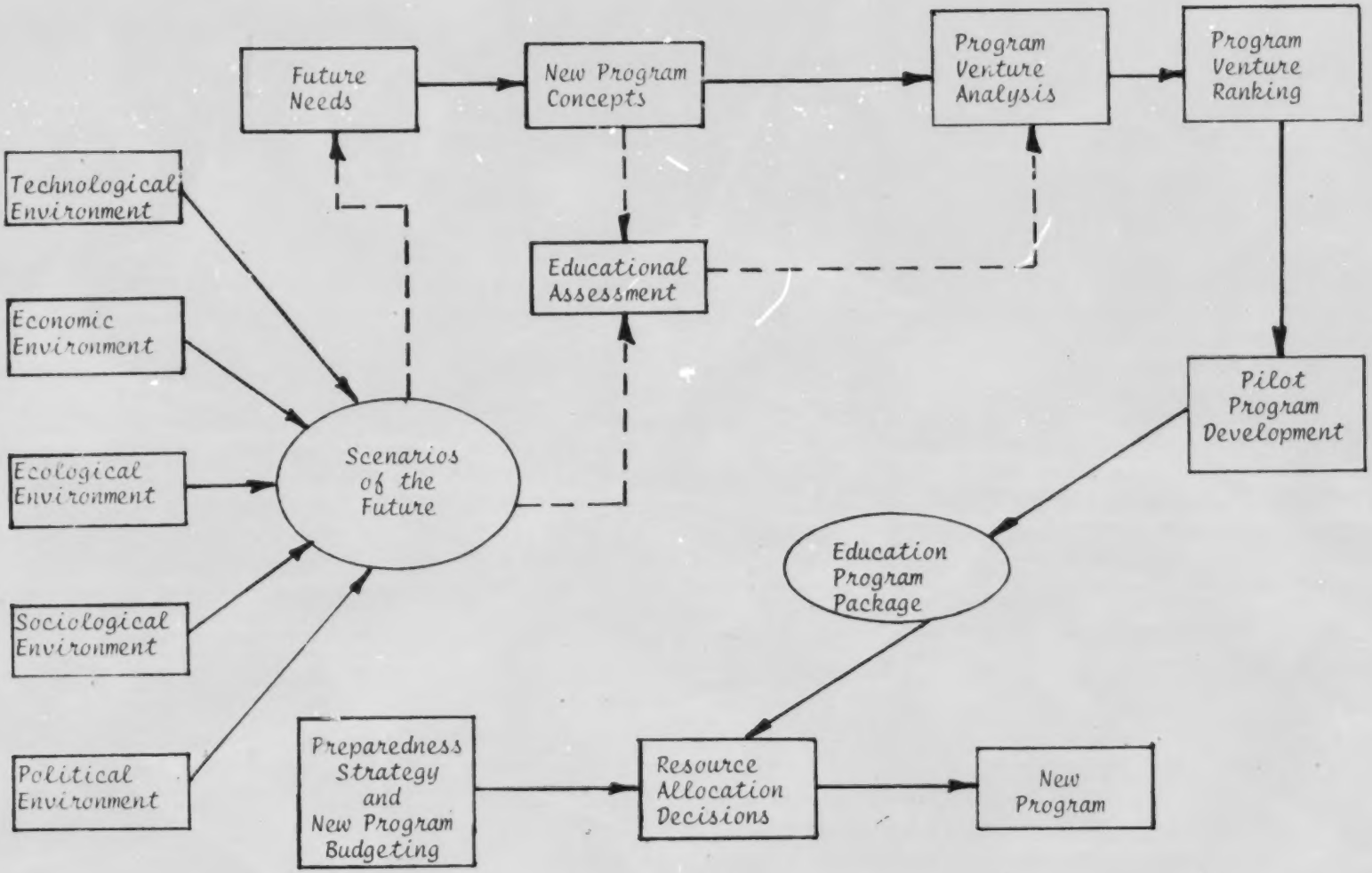
Clearly, universities need to plan and manage their resources with the utmost skill and professionalism. In general, it appears that such tools as management science, economics and systems analysis which are offered in the curriculums of most universities have been applied everywhere but in the universities own sphere.

To provide a point of departure, consider the following gross structure depicting the basic elements necessary for academic planning and development which has been adapted from a new venture planning model.[6]

The process begins with the projected trends of the technological, economic, ecological, sociological and political environments and leads to the construction of a scenario of the future. The future needs are ascertained from this scenario and new program concepts to meet these needs are evolved. The educational assessment process evaluates the new program concept against the resources available and/or required, the likelihood of their accessibility and attainment and results in a program venture ranking. If warranted by the ranking, pilot program development is initiated. This may take the form of an elective course, a sequence of courses etc., from which a more encompassing educational program package is eventually formulated. In conjunction with the point of program venture ranking, a preparedness strategy and budgeting forecast should be developed to insure the availability of resources at the time the program package is ready for implementation.

The magnitude of effort required for this type of academic planning is proportional to the degree of preparedness the university seeks. If no demand exists for its graduates, if declining enrollments are of small consequence, if public confidence in the relevancy of its programs are

[6]Blackman, A. W., Jr., (Ref. 13, Pg. 3).


Future Needs
New Program Concepts
Program Venture Analysis
Program Venture Ranking
Technological Environment
Economic Environment
Ecological Environment
Sociological Environment
Political Environment
Scenarios of the Future
Educational Assessment
Pilot Program Development
Education Program Package
Preparedness Strategy and New Program Budgeting
Resource Allocation Decisions
New Program

of little concern, etc., the university can meet these problems on a "crisis planning" basis. There are, however, other acceptable degrees of planning even though the idealistic ultimate complete perception may not be practically attainable.

Methodologies suitable for planning in the academic environment are decision analysis, forecasting, system dynamics and others.

Decision analysis is an outgrowth of operations research and management science. It has resulted from combining techniques of systems analysis (applicable to the analysis of the dynamic behavior of complex situations) with techniques of statistical decision theory (applicable to simple situations involving uncertainties) to produce techniques applicable to complex dynamic systems involving uncertainties in many input variables. The objective of decision analysis is to apply logical, mathematical, and scientific procedures to those decision problems which:

(a) involve a significant portion of an organization's resources,

(b) have long-term effects on a firm's future success, and

(c) are characterized by uncertainty in many of the factors important to the decision.

The various methodologies which relate to technological forecasting may be broadly classified as exploratory, normative, or dynamic. Exploratory (or capability-oriented) techniques are based on extrapolations of historical technological trends in order to

forecast future technological capabilities. They are, therefore, forecasts which are based on the past.

In contrast, normative (or needs-oriented) forecasting techniques are based on the future. Their application requires compilation of a description of the future and extraction of the most probable conditions. From these conditions, the technological advances that will be needed are identified, technical targets established, and research programs undertaken to achieve them. In essence, an analysis of future needs, priorities, and funding becomes a technological forecast.

Dynamic forecasting attempts to join exploratory and normative components into a feedback cycle. By building dynamic computer models which replicate real systems, forecasts may be obtained through simulation.[7]

An excellent appraisal of exploratory and normative forecasting techniques as presented by Roberts[8] is presented in Appendix A.

The final methodology to be advanced here is System Dynamics. This methodology has been developed at the Massachusetts Institute of Technology by members of the Sloan School of Management under the direction of Dr. Jay Forrester. As indicated by Roberts[9], it integrates the essential elements of exploratory and normative forecasting with time and feedback systems.

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[7]Ibid., Pg. 3.

[8]Roberts, E. B. (Ref. 14, Pg. 247-48, 255-56).

[9]Ibid., Pg. 256-257.

In a subsequent section of this report, the philosophy and methodology of System Dynamics are presented with interpretations and variations reflecting this author's viewpoints. It represents the methodology to be employed in this study of the relationship between engineering and engineering technology.

In a final note, all forecasting techniques represent varying degrees of utility, creditability and difficulty. The choice of methodology is largely a trade off between available resources, need and time. However, it would appear that little justification exists for not implementing as a minimum effort intuitive and formal trend methods in any institution of higher education.

SYSTEM DYNAMICS

PHILOSOPHY - METHODOLOGY

SYSTEM DYNAMICS
PHILOSOPHY - METHODOLOGY

The System Dynamics philosophy is predicated on the hypothesis that all events are system oriented in a time dependent frame of reference. Systems, in the System Dynamics view, are comprised of a series of sequential individual operations, events or actions within an interactive framework of determinable form. The individual happenings influence the system and the system, in turn, influences the individual happenings.

System Dynamics provides a conceptual framework within which the individual elements or variables are allowed to interact with each other through time as they do in the real world. The dynamic model, which is an inherent feature of the System Dynamics approach, allows one to examine the inter-relationships and forsee the effects of individual happenings, policies, etc. on the overall system. The dynamic model will be limited by the knowledge available and the assumptions pertaining to the important relationships; it is evident, however, that the dynamic model provides a better understanding of the complex interdependence of those factors that influence system behavior.

The System Dynamics methodology utilizes the following fundamental elements to insure viable results:

DISCIPLINE SCIENCES

INFORMATION FEEDBACK

DECISION PROCESSES

SYSTEM SIMULATION

Discipline sciences provides a rigorous base for the mathematical or physical modeling of complex interacting systems. Information feedback is utilized

to incorporate decisions or events which result in actions which affect the system environment and thereby influence future decisions or events. Decision processes are included in the system model to provide an orderly basis for policy formulation and evaluation. System simulation provides a mechanism for experimentation on the system model instead of the real system.

In application, the System Dynamics methodology is implemented sequentially in the following manner:

PRELIMINARY SYSTEM ANALYSIS employs the appropriate discipline sciences to determine the primary variable relationships in the system. Sub-system feedback loop diagrams are developed and combined to yield a basic system of feedback loops relating the primary variables, their interactions and consequent feedback in the overall system.

SYSTEM STRUCTURE DEVELOPMENT proceeds from the basic loop structure. A detailed analysis establishes the required loop relationships between the variables, incorporates the required information feedback, decision processes, delays, flows etc. Evolving from system structure development is a capaciously oriented system diagram depicting state, rate, and auxiliary variable relationships with multiple feedback loops. This evolution follows as in the preliminary system analysis, that is, from sub-systems development with final incorporation into an overall system.

TASK OUTLINE delineation follows system structure development. The detail provided in the system structure serves as a focal point for the definition of specific tasks, input data available, variables to be related, task-function descriptions and desired output variables.

MATHEMATICAL MODELING utilizes the output resulting from task accomplishment. Functional relationships are established between the input data and the desired output. The nature of the events and data influence the type of functional relationships forthcoming. These functional relations may be deterministic or stochastic, singular or pluralistic.

SYSTEM SIMULATION in the majority of cases is performed via computer. Computer simulation models are developed from the mathematical models to provide a rapid, convenient method of evaluating interactions, system behavioral patterns, alternative policies and optimization. The computer simulation model structure is developed in hierarchial form utilizing sub-systems. This type of structure provides program control options for sub-system simulation and/or overall system simulation as desired.

PRELIMINARY SYSTEM ANALYSIS

PRELIMINARY SYSTEM ANALYSIS, as previously stated, employs the appropriate discipline sciences to determine the primary variable relationships in the system. Sub-system feedback loop diagrams are developed and combined to yield a basic system of feedback loops relating the primary variables, their interactions and consequent feedback in the overall system.

A preliminary analysis of the primary variables involved in this study of the engineering - engineering technology interface results in five basic feedback loops. One additional feedback loop relating pertinent common elements and their interaction with engineering and engineering technology was deemed appropriate for clarification. The six feedback loops are:

- *THE NEEDS - TECHNOLOGY APPLICATIONS LOOP*
- *THE TECHNICAL MANPOWER UTILIZATION - RESOURCES LOOP*
- *THE TECHNICAL MANPOWER DEMAND - GRADUATES LOOP*
- *THE TECHNICAL EDUCATIONAL FUNDING - UNIVERSITY RESOURCES LOOP*
- *THE NEEDS - POPULATION - ENROLLMENT LOOP*
- *THE ENGINEERING - ENGINEERING TECHNOLOGY INTERACTION LOOP*

The individual loops are presented diagrammatically and followed by a verbal description of the relationship between the variables. The verbal presentations are not intended to be all inclusive. Taken in context, the descriptions furnish an overview and relegate the details to the system structure development and mathematical modeling phases of this study.

Presentation of the results of the preliminary system analysis proceed in the reverse order of the actual development. Initially, the overall system structure diagram provides a visual display of all the primary variables and

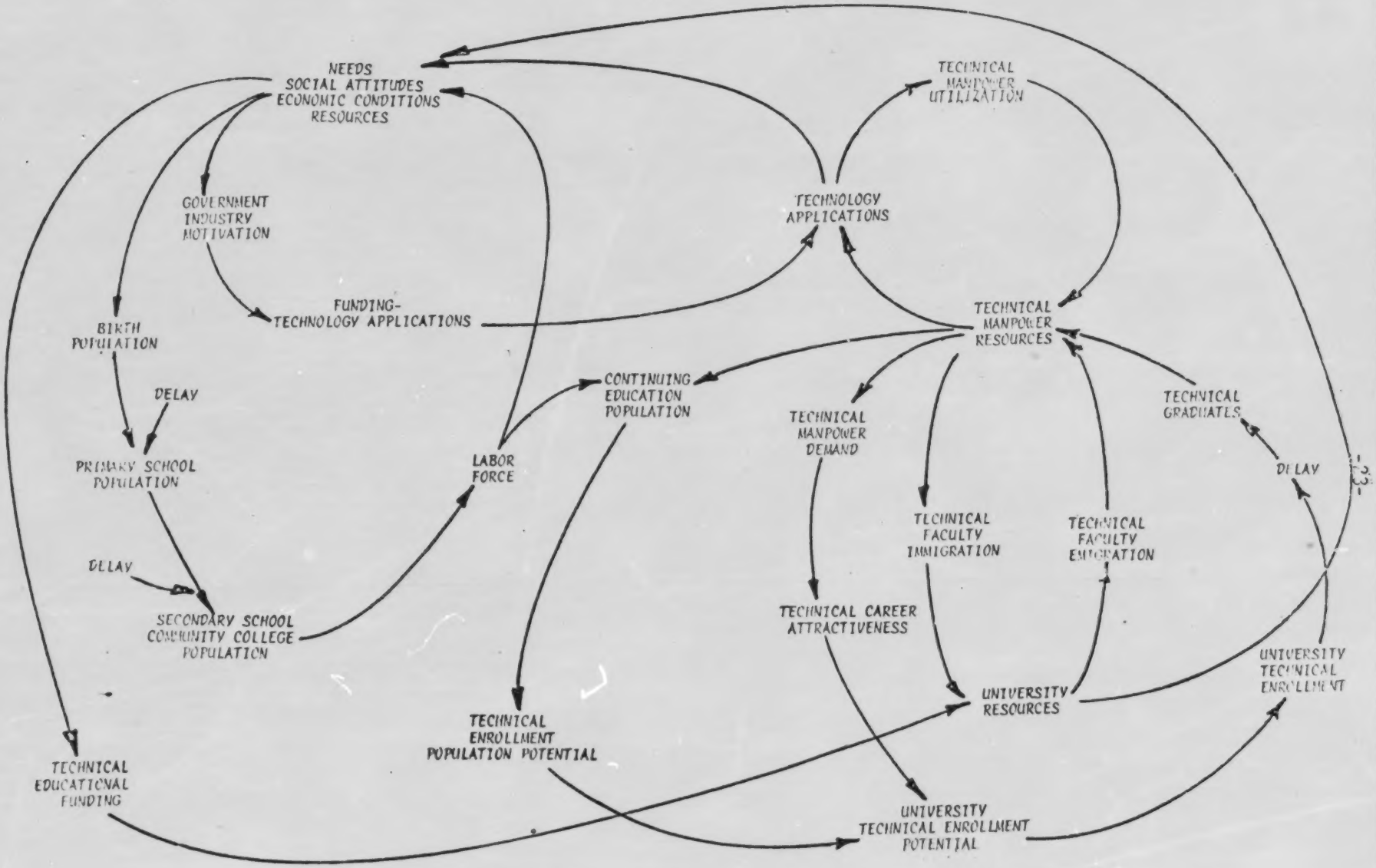


FIGURE 1. BASIC SYSTEM STRUCTURE

the interacting loops. After this system orientation the individual loops are examined and discussed. A reexamination of the overall system structure following the individual loop studies will reinforce the concept of system interaction and feedback.

The overall system structure illustrates the five basic feedback loops which are interlocked through related variables. A discussion limited to loops 1, 2 and 3 should provide sufficient clarification to allow one to proceed through the remainder of the system.

In the Needs - Technology Applications Loop (1), an increase in technological needs (national, state, local) provide the motivation for government or industry to take action resulting in technology applications to satisfy those needs.

The increase in technology applications results in an interaction with the Technical Manpower Utilization - Resources Loop (2). The increase in technology applications results in increased technical manpower utilization which decreases the technical manpower resources which limits the technology applications. This, in turn, increases the technological needs.

The decrease in technical manpower resources results in an interaction with the Technical Manpower Demand - Graduates Loop (3). The decrease in technical manpower resources results in an increase in the technical manpower demand, enhances technical career attractiveness and increases the potential for university technical enrollment. The university technical enrollment increases, and after a delay, increases the number of university technical graduates. The increase in graduates increases the technical manpower resources which increases the technology applications which acts to reduce the technological needs.

The preceeding discussion of the interactions between the loops comprising

the system will now be supplemented by an examination of the individual loops and the role of the primary variables. In the majority of cases hypotheses pertaining to the loops are advanced. The stated hypotheses are not inviolable, nor are they intended to be. The validity of the assumptions pertaining to the individual loops and indeed the system itself reside in the results of system simulation and verification with the real world.

THE NEEDS - TECHNOLOGY APPLICATIONS LOOP

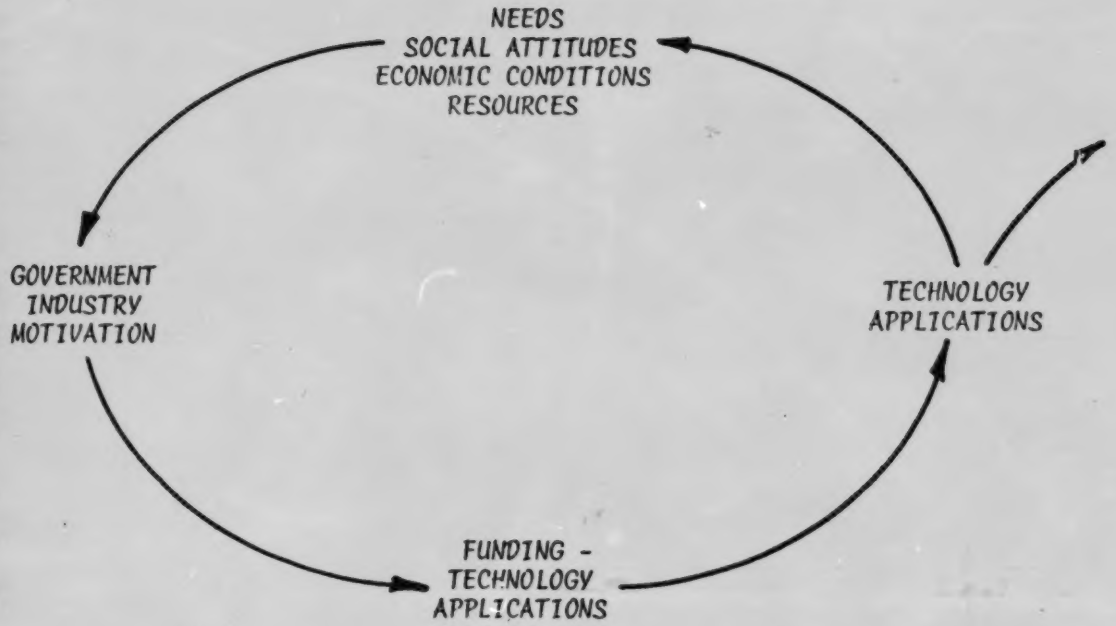


FIGURE 1. THE NEEDS - TECHNOLOGY APPLICATIONS LOOP

THE NEEDS - TECHNOLOGY APPLICATIONS LOOP relates the variables of societal needs, social attitudes, economic conditions and resources to government-industry motivation, funding of technology applications and technology applications.

The hypotheses pertaining to this loop assume that in order to meet its needs, society will utilize existing operational technology. Furthermore, as society grows more complex, it continuously creates new needs which in turn provide opportunities for the development of new technologies. Awareness of new technological developments in turn influences societal expectations.

The parameters of social needs, expectations and resources are expected to continue to influence the exponential growth of technology. This growth pattern will be substantially altered only if knowledge is bounded or societal attitudes and pressures divert the flow of resources from new technological endeavors.

Technology has been the mainstay of our economy for many years and has influenced the cultures of the world to a major degree. National goals become meaningless unless the forces of technology can be brought to bear on the problems associated with attaining those goals. Recognition of these facts preclude any major diversions of resources from technological endeavors for extended periods of time. Rather, technology will be called to task to develop new and meaningful ways to weigh both the benefits and possible side effects of technology on society and its environment and to provide optimized alternatives. Thus, once again the parameters of social needs and expectations reappear to influence technological growth.

THE NEEDS - TECHNOLOGY APPLICATIONS LOOP is a negative feed-back loop that maintains a balance between needs and technology applications. An increase in needs coupled with positive social attitudes, supportive economic conditions and resources increases government and industry motivation to fulfill the needs of society. This increases governmental and/or industrial funding for technology applications which, in turn, increases the applications of technology. The technology applications, successfully culminated, decreases the needs.

The successful culmination of a technology application, it is to be noted, may provide positive or negative reaction (feed-back) in social attitudes, economic conditions or resources. For example, the application of technology to agriculture and food processing leads to increased yields but questionable management controls result in temporary shortages leading to adverse social attitudes; a technology application may increase technological know-how (a resource) but decrease critical raw materials (another resource).

The needs - technology applications loop as presented here provides a general categorization that is unsuitable for definitization of specific needs. However, it does serve as an indicator of tasks to be performed. How does one perceive future need? To some extent, these needs may be perceived by an awareness to areas of developing criticality evidenced by advance warning indicators; for example, energy, natural resource depletion and ecology. Future needs are also perceived by evaluating development trends in areas such as employment, recreation, education, medical, transportation, durable and non-durable goods, defense, etc.

By selective processing areas to be explored further may be designated on a ranked level. Based on the level of rank, the decision process may authorize preliminary system analysis for selected areas to ascertain the needs and trends to a higher degree. Results from the preliminary system analysis when evaluated, will provide a basis for decision as to whether or not system structure development and simulation are warranted. System structure development and simulation if implemented would be monitored thereafter and revisions incorporated to reflect the dynamic state of affairs. Thus, technological educational development needs would be paced to ever fluid needs, government - industry motivation and funding indicators and projected technology applications.

THE TECHNICAL MANPOWER UTILIZATION - RESOURCES LOOP

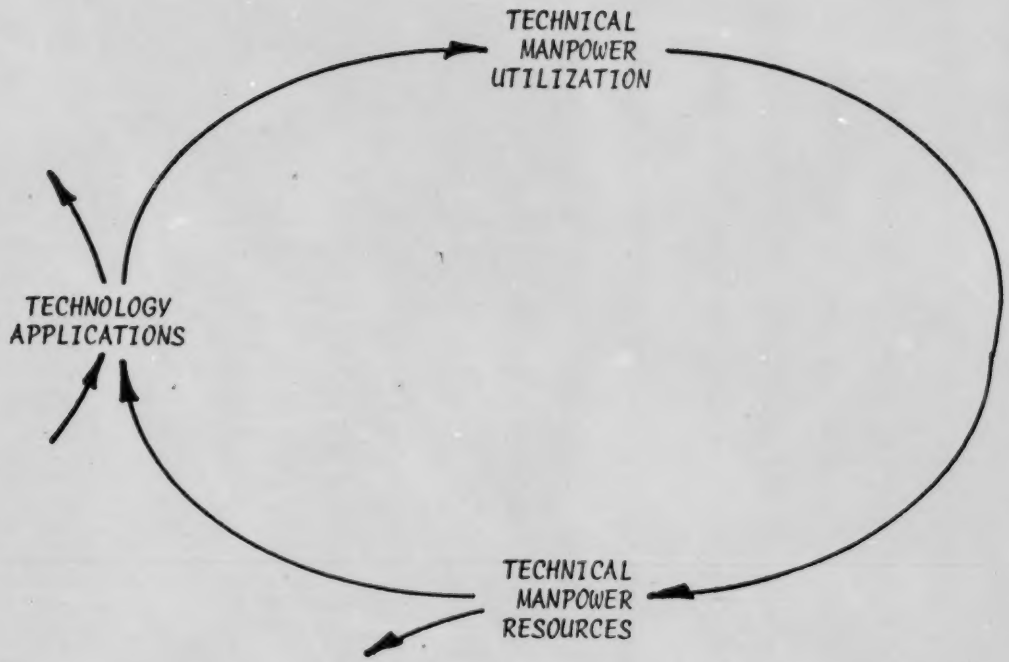


FIGURE 2. THE TECHNICAL MANPOWER UTILIZATION - RESOURCES LOOP

THE TECHNICAL MANPOWER UTILIZATION - RESOURCES LOOP indicates the qualitative relationship of technology applications to technical manpower utilization and technical manpower resources.

The technical manpower utilization - resources loop is a negative feedback loop that balances technology applications and technical manpower resources. In response to the needs demand the implemented technology applications result in an increase in technical manpower utilization. The increased utilization of technical manpower is reflected in an increase in technology applications satisfying the needs but simultaneously decreasing the available pool of technical manpower resources.

The inputs to this loop are the breadth and magnitude of the perceived technology applications as determined from the needs - technology applications loop. If the inputs are selective with respect to specific areas of technology applications then the technical manpower utilization variable must provide proper consideration for transfer processes for comparable skills, retraining etc., and the delays associated therewith. A comparative study of present utilization, existing resource expertise and potential expertise in process with the projected demand provides another decision base for academic allotment of resources.

THE TECHNICAL MANPOWER DEMAND - GRADUATES LOOP

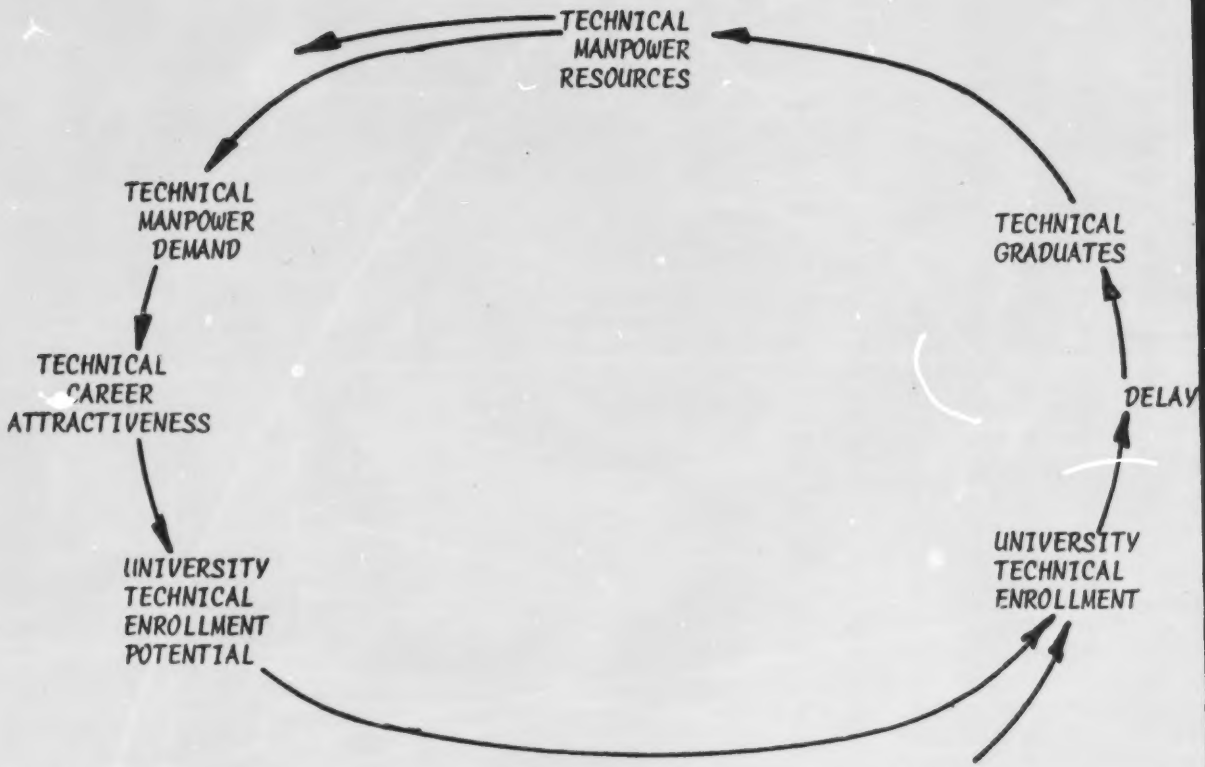


FIGURE 3. THE TECHNICAL MANPOWER DEMAND - GRADUATES LOOP

THE TECHNICAL MANPOWER DEMAND - GRADUATES LOOP depicts the basic variables and their inter-relationship in effecting supply and demand of technical manpower.

The technical manpower demand - graduates loop is a negative feedback loop that provides the balance between technical manpower resources and the technical manpower demand. Assuming a reduction in available technical manpower resources gives rise to the expectation of an increased demand for technical manpower. This enhances the attractiveness of a technical career with a consequent increase in the potential for university technical enrollment. This is reflected in increased university technical enrollment. Allowing for attrition and the inherent delay in satisfying degree requirements the response to the technical manpower demand subsequently appears as an increase in technical graduates which increases the available technical manpower resources.

If the technical manpower demand variable is properly perceived on a realistic basis with due accounting for the significant feedback effects of the previously indicated variables, the cries of panic proclaiming the forthcoming engineering shortage would be abated. Of greater significance however, would be the enhancement of technical career attractiveness provided by realistic appraisals of technical manpower demand in its various aspects. This would provide an incentive for enrollment and the pursuit of goals culminated in a rewarding career both financially and intellectually. More implicit than explicit, the feedback path from technical manpower resources to technical career attractiveness none the less constitutes a potent force for attitudinal

response to a technical career. Technical graduates may have some justification for embitterment if their educational efforts are reflected by improper utilization and transient employment.

Using the projected technical manpower demand, the tasks associated with this loop are the forecasting of university technical enrollment and subsequently the graduates.

THE TECHNICAL EDUCATIONAL FUNDING - UNIVERSITY RESOURCES LOOP

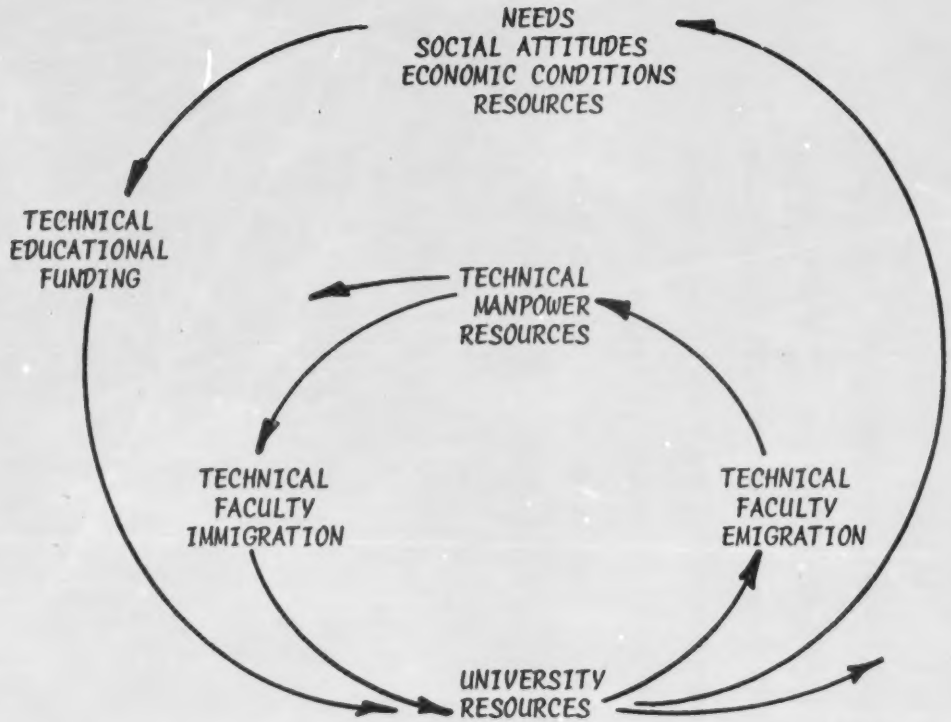


FIGURE 4. THE TECHNICAL EDUCATIONAL FUNDING - UNIVERSITY RESOURCES LOOP

THE TECHNICAL EDUCATIONAL FUNDING - UNIVERSITY RESOURCES LOOP is a negative feedback loop that depicts the relationship between needs, technical educational funding and university resources. The hypothesis assumes that as the need for technology applications and the technical manpower utilization increase the resultant decrease in technical manpower resources will be reflected in a supportive social attitude and funding for technical education.

The necessity for futuristic planning and development is implicity evident in the variables of faculty immigration and emigration. With adequate projections on needs and technological developments, faculty selection may be more purposeful and directed with respect to academic programs and goals. More meaningful evaluation as to the resources to be acquired and their subsequent justification are provided for by a quantitative, realistic analysis of forthcoming university needs that are supportive of national, state or local needs.

THE NEEDS - POPULATION - ENROLLMENT LOOP

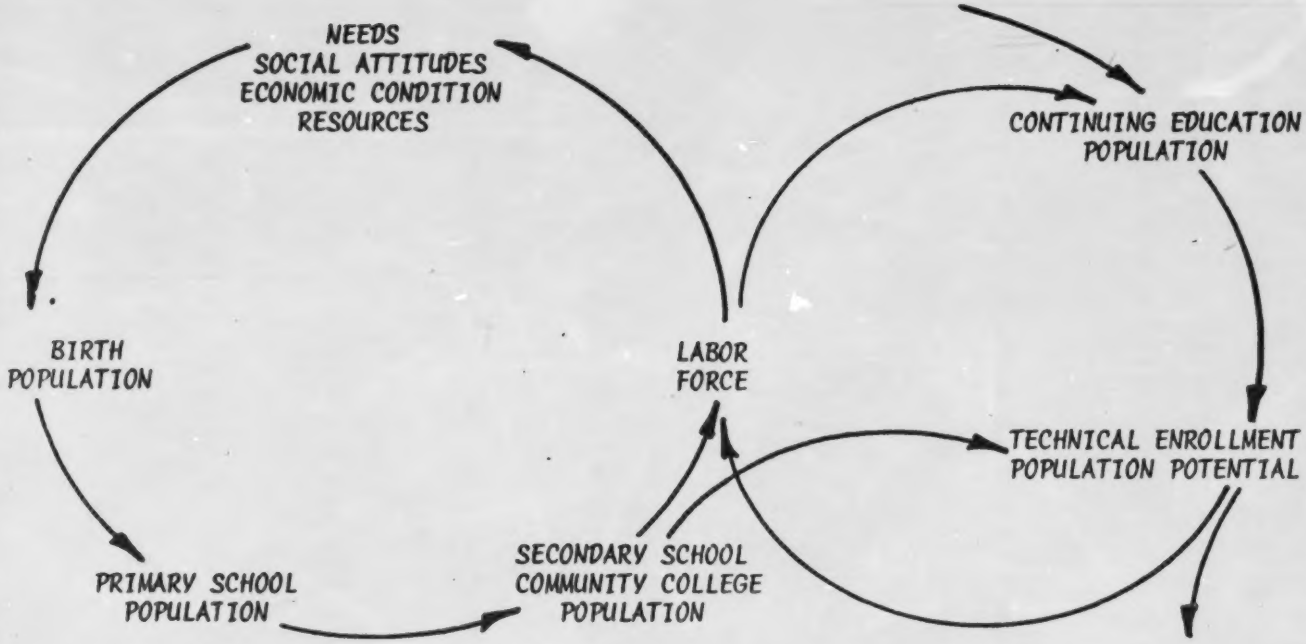


FIGURE 5. THE NEEDS - POPULATION - ENROLLMENT LOOP

THE NEEDS - POPULATION - ENROLLMENT LOOP relates the variables of birth population, primary, secondary and community college population with the variables of labor force, continuing education population and technical enrollment population potential. Although cast as one loop this subsystem actually consists of two interacting loops. This provides a basis for examining the relationships between the major components of educational emphasis existing today, namely, career education, continuing education and higher education.

The tasks associated with this loop are the projections of births and the premises for those projections based on social attitudes and probable future economic conditions. The census bureau projections for the last three years have been adjusted downward three successive times and an additional downward adjustment appears in the offing. The decline of births, of course, will slow the primary school population growth and eventually the secondary, community college and higher education population in the years to come. Additional projections that require evaluation are the claims that community college growth rates will surpass those of four or more year institutions in the next few years.

Currently, the fastest growing employment area is in the field of services. This is engendered in a large measure by a shift of a large portion of the american economy to services and the continuing rise in the public sector as a major area of employment. The labor force as constituted in this loop encompasses all but the technological

labor force. The increasing emphasis on career education programs and its consequent impact on technological higher education is a variable that merits inclusion in this subsystem.

The continuing education variable in all its various aspects is worthy of attention because of the continued exponential growth trend of knowledge in all forms and the projected increase in the demand for this type of education in the future. The foregoing variables are significant for the determination of the population potential of technical enrollment in the forth coming years.

THE ENGINEERING - ENGINEERING TECHNOLOGY INTERACTION LOOP

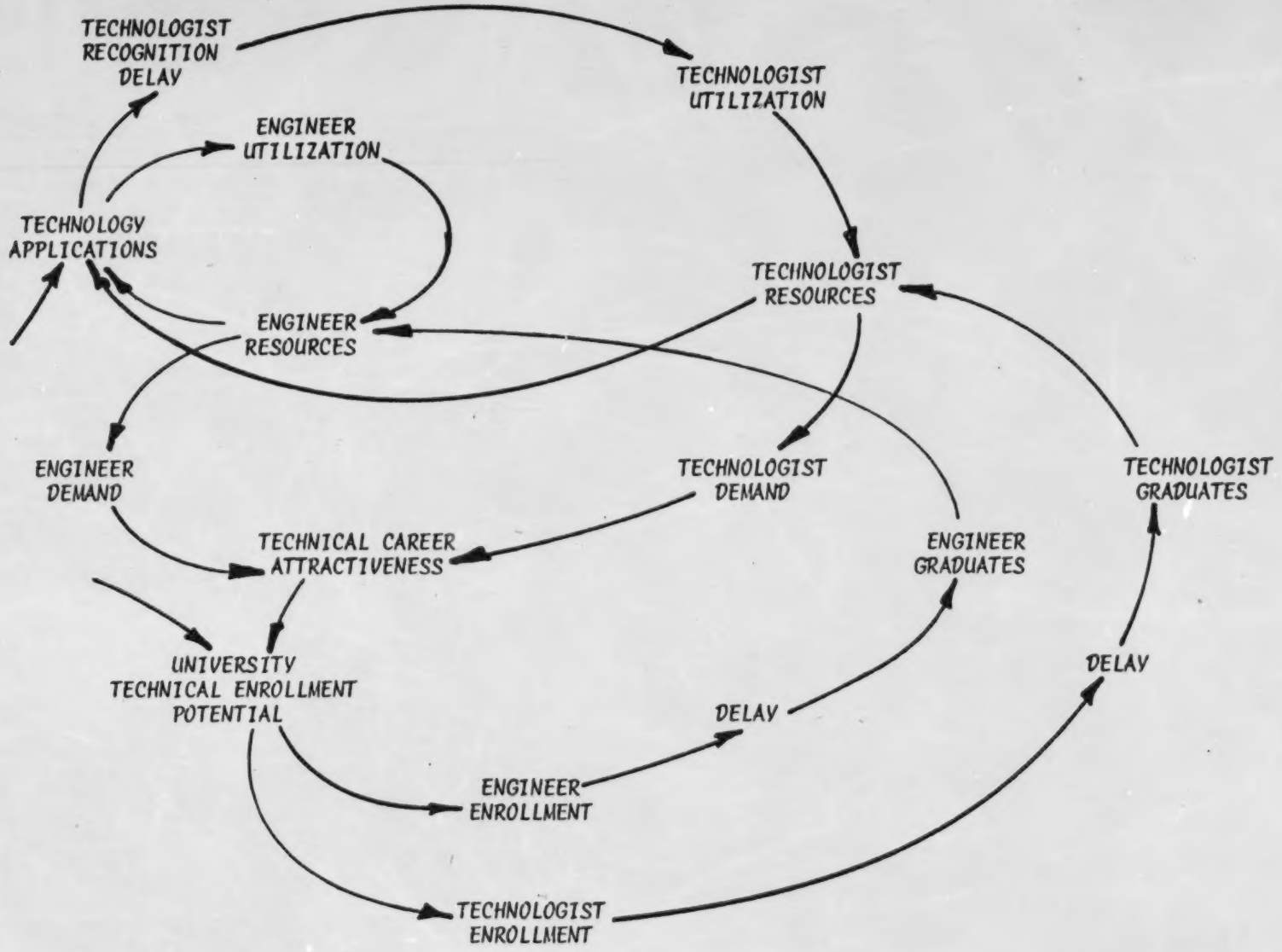


FIGURE 6. THE ENGINEERING - ENGINEERING TECHNOLOGY INTERACTION LOOP

THE ENGINEERING - ENGINEERING TECHNOLOGY INTERACTION LOOP combines elements of the *TECHNICAL MANPOWER UTILIZATION - RESOURCES LOOP*, *THE TECHNICAL MANPOWER DEMAND - GRADUATES LOOP* and *THE NEEDS - POPULATION - ENROLLMENT LOOP*. Its purpose is to illustrate the basic relations between Engineering and Engineering Technology in those loops.

The hypotheses pertaining to this loop are as follows:

- An increase in technology application needs will result in increased engineer utilization depleting the engineer resources and satisfying the applications needs initially. As the need for technology applications resumes, industry and government, faced with a depleted engineer resource and rising engineering manpower costs, will (hopefully) evaluate the technical skill levels required for specific technology applications. This evaluation, if initiated, could signal the end of the mythical "engineering shortage" created by the high level of under-utilization of engineering capability that has existed for many years.

- Following an inherent delay in recognizing the capabilities of the engineering technologist, the decreasing availability of engineers and their increasing recruitment and retention costs will result in increased utilization of the technologist for engineering tasks appropriate to the technology level.

- The recognition of the engineering technologist and increased utilization of this technical manpower source will increase the technologist demand and have an adverse effect on the demand

for engineers to employ their skills at the technologist level. The engineer demand will rise only if the available engineering technologist resource is unable to fill the demand for technical manpower at the technologist level and/or the technology applications require the higher level engineering skills and sophistication for their resolution.

- Assuming national needs and economic conditions are such to warrant a high level need for technology applications, the demand for engineers and engineering technologists will increase the attractiveness of a technical career, and raise the university technical enrollment potential resulting in enrollment in engineering technology and engineering programs. The variations in the Engineering - Engineering Technology enrollments will undoubtedly reflect transitory cyclic variations as the variables of need, technology application levels, recognition and utilization delays shift with time. These variations and the possibility and consequences of decline in technology applications require a detailed examination of the sub-systems associated with this loop and their interactions within the overall system structure.

SYSTEM STRUCTURE DEVELOPMENT

The *PRELIMINARY SYSTEM ANALYSIS* established the relationship between the primary variables in the engineering-engineering technology interface by a series of sub-system feedback loops depicting interactions and consequent feedback in the overall system.

In conjunction with that analysis, forecasting methodologies and the concepts of ratio analysis were advanced as viable techniques in the system dynamics approach to the evaluation of time dependent events in an interactive framework.

The second stage of the system dynamics methodology, as previously noted, is system structure development. From the basic sub-system feedback loops of the preliminary system analysis a detailed study leads to the development of sub-system structure. Evolving from this process is a capaciously oriented system diagram depicting state, rate and auxiliary relationships with multiple feedback loops and information flows.

Proceeding from the resultant system diagram the relationship between variables, institutional policies, process delays, etc. are programmed to form the computer simulation model of the sub-system. The computer simulation model output provides data for the analysis of current and predicted events and trend developments. This output data presented in appendices B and C for the sub-systems developed.

Prior to introducing the actual sub-systems, the basics of system structure development are provided in an abbreviated format as an aid to interpretation of system diagrams.

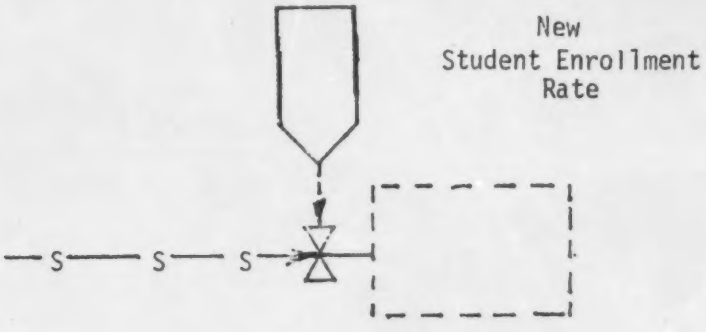
BASICS OF
SYSTEM STRUCTURE DEVELOPMENT

BASICS OF SYSTEM STRUCTURE DEVELOPMENT

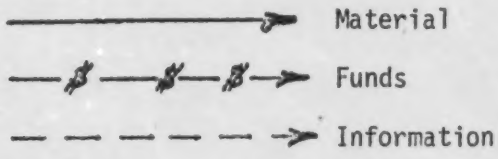
SYSTEM STRUCTURE DEVELOPMENT establishes detailed system diagrams depicting state, rate and auxiliary variable relationships with multiple feedback loops. These loops relate information, decision processes, delays, flows etc. The following type of flow diagrams and symbols are representative of those used throughout this study.

A state variable is represented by a simple block with a designation label inside. A state variable represents an accumulation of resources: inventories (of goods or ideas), balances of funds, total student enrollment, etc.

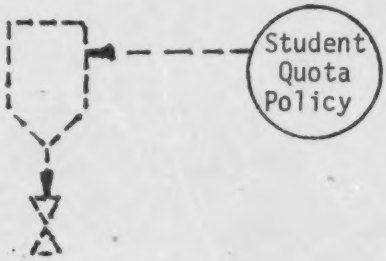
A rate variable controls the flows within the system: information, materials, manpower, funds, graduating students, etc. Here, one type of symbol is used to represent the actual decision function (rate variable) that controls the flow and the second symbol indicates the flow itself.



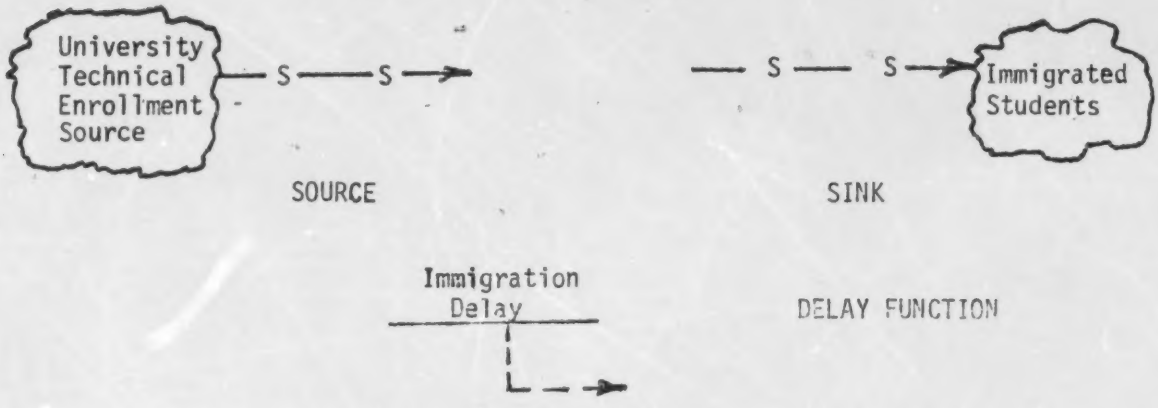
Various types of flow symbols may be utilized and the meanings will be clear from the context. The more common flow symbols are as follows:



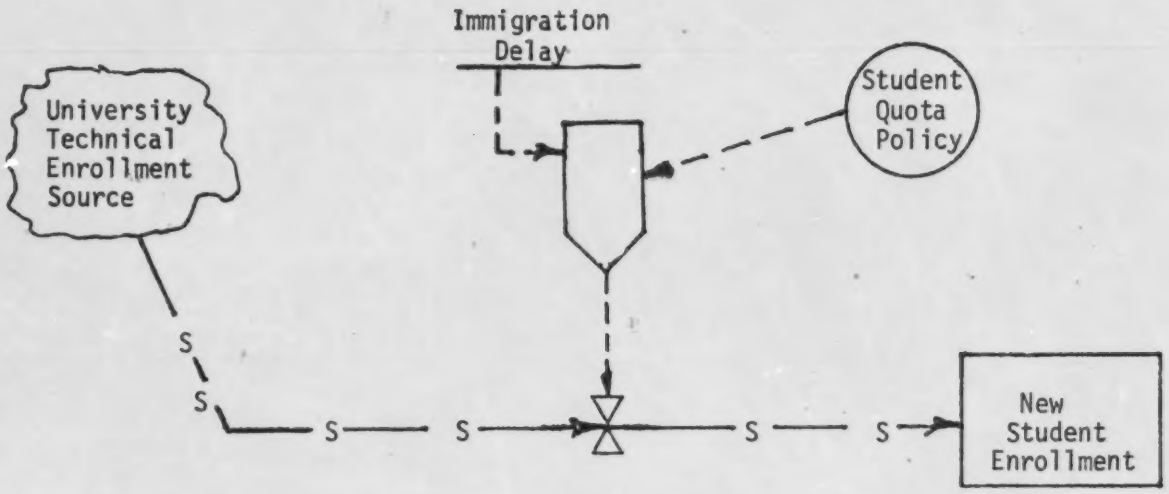
Frequently, a rate variable (the decision function) is clarified if the decision function is represented by its elementary parts. These parts are designated as auxiliaries and are represented by circles -- thus



Additional symbols frequently used are a cloud-like symbol to indicate a source or sink for some flow and a solid underlining of a parameter or constant.



The symbols shown thus far are organized into a simple system diagram which typify the method employed throughout this study.



In the following pages of this section the various sub-systems comprising the overall system evaluated in this study are developed in detail using the aforementioned flow diagram symbols.

SUB-SYSTEM

SIMULATION MODELS

SUB-SYSTEM SIMULATION MODELS

GENERAL

The order of development of sub-system models is arbitrary provided the constraints of time, funding and need are not paramount considerations. There are advantages to proceeding from the so called "top down" approach which utilizes gross variables and subsequently adds more detailed sub-systems. However, the development of sub-systems may also proceed on the basis of predicated order of need and designed for immediate implementation, while overall system development proceeds. In this study the latter approach was taken; therefore, the presentation of the sub-systems are in the order of development as determined by need.

The various sub-system designs will, of course, reflect the operating procedures and policies of the institution they represent. Variations may be implemented by revising the simulation model to fit other institutions.

California State Polytechnic University, Pomona is one of the nineteen institutions comprising the California State University and Colleges. The School of Engineering conducts programs in engineering, engineering technology and Master of Engineering.

The academic year is officially constituted as four academic quarters; summer, fall, winter and spring. Unofficially, the normal academic year

is usually considered as consisting of three quarters; fall, winter and spring. The sub-systems presented in this study reflect the foregoing academic year structure and the operating procedures and policies of this University.

UNIVERSITY TECHNICAL ENROLLMENT

SUB-SYSTEM

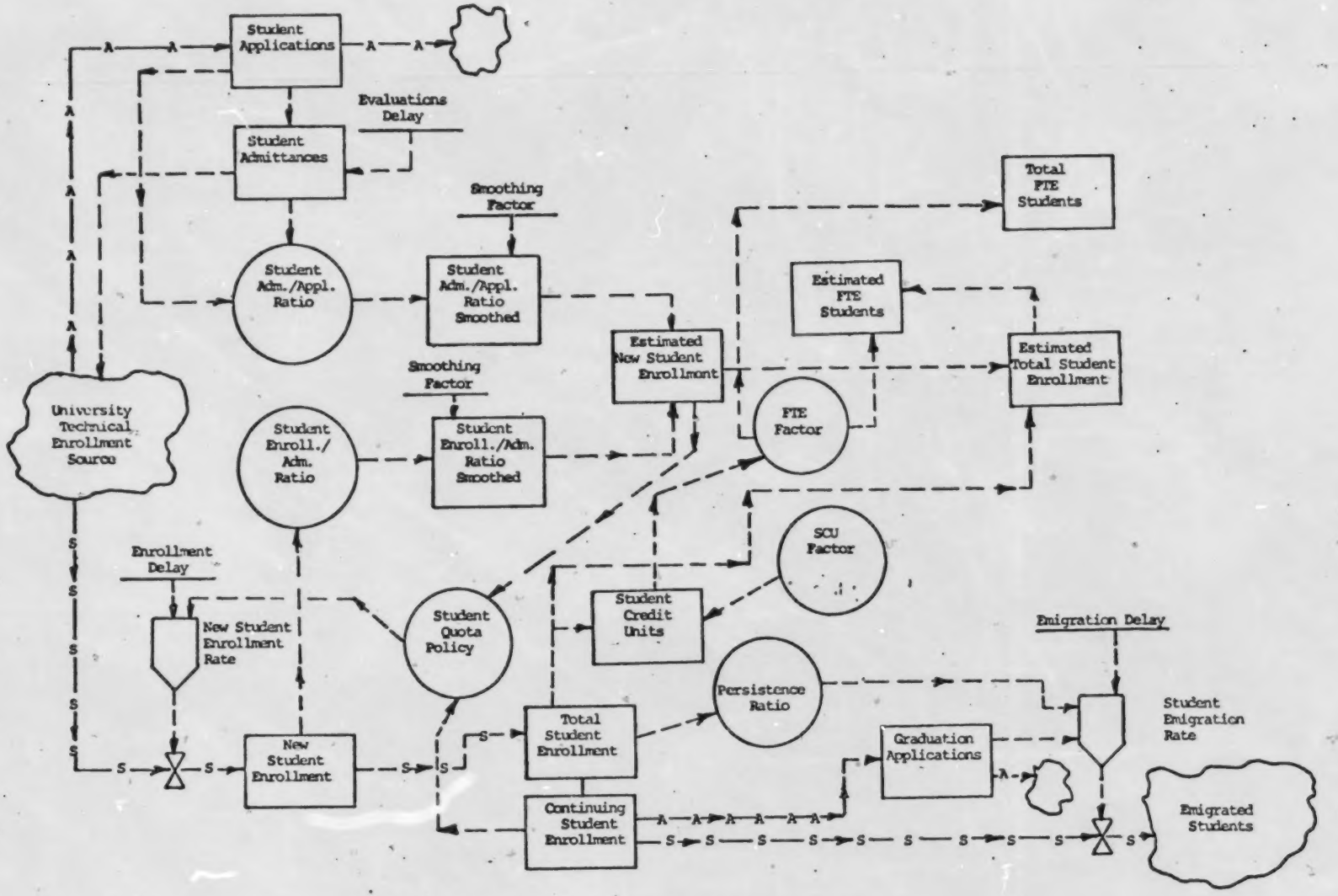


Figure 1. *"University Technical Enrollment Subsystem"*

UNIVERSITY TECHNICAL ENROLLMENT SUB-SYSTEM

THE UNIVERSITY TECHNICAL ENROLLMENT SUB-SYSTEM is depicted in Figure 1. The computer simulation output for this sub-system is designed in four basic sections. Output data is provided for the total School of Engineering and the individual departments.

Section - 1 Applications-Enrollments-Graduates provides a ten year history of applications, admissions, enrollments and graduates and projections for the next academic year.

Section - 2 Profiles-Persistence Ratios presents cross section profiles on student enrollments, class makeup and persistence of students for the academic year for a six year period by quarters.

Section - 3 Ratio-Trends Analysis provides a six year period by quarters, of regular and limited students, the average unit load taken by these students and the full time equivalent student interpretation.

Section - 4 Ratio-Trends Analysis summarizes the quarterly data of Section -3 on a yearly basis to provide enrollment and class profiles. In addition, Fall quarter enrollment and class profiles are provided.

SECTION - 1 APPLICATIONS-ENROLLMENTS-GRADUATES

The computer simulation output for Section - 1 provides a ten year history of fall quarter applications, admissions and new enrollments and the graduates for that academic year. The primary ratios of admissions/applications and new enrollments/admissions provide a basis for evaluating admission practices and the extent of spurious applications. The tabular output is supplemented with a graphical display of applications, admissions, enrollments and graduates versus academic year.

The lower table of Section - 1 provides year to date actual values of applications, and admissions versus month for the fall quarter as data becomes available. The projection data on applications, admissions and enrollment provides a six months lead time on enrollments.

The primary ratios of admissions/applications and enrollments/admissions reveal that the number of students that actually enroll after being admitted to the University, School of Engineering, varies between 74% and 83% with an average value of 78%.

Shortly after the fall quarter of 1972, one of the major concerns of the University was the decline in enrollments. The figures for the School of Engineering reflect a portion of that enrollment drop. In the case of some other schools in the University, the enrollment drop was quite severe and concerted efforts to increase enrollment and student credit units were undertaken. The admissions/applications ratio reveals that preceeding the actual fall enrollment, the admissions process was somewhat stringent

after a three year growth rate. That is, the ratio of admissions/applications were 76%, 80% and 84% and then declined to 80% which only aggravated the enrollment drop. The pressures to increase enrollment are reflected by the 1973 ratio which shows a substantial increase to 87%. Although these figures apply only to the School of Engineering, they are a reflection of the events within the total University. Monitoring this ratio and the persistence ratios of Section - 2 over the next few years should provide further insight to the consequences of these events.

SECTION - 2 PROFILES-PERSISTENCE RATIOS

The tabular output for Section - 2 provides a quarter by quarter profile of the type of enrollment and class make up in the School of Engineering over a six year period.

The enrollment profile consists of first time freshman (Frosh), transfer students (Tsfrs), returning students (Rtnd) and continuing students (Cont). The data clearly reveals a steady growth of transfer student enrollment and decline in first time freshman enrollment. The factors contributing to this situation will be evaluated in sub-systems relating to the needs-population enrollment loop advanced in the preliminary systems analysis.

The class profile consists of the usual undergraduate categories plus an additional class designated as limited students (Lmtd) taking a minimum unit load. From the data it is evident that the class profiles are compacted at the senior level. This is further confirmed by the persistence ratios which calculate the persistence from the fall through spring quarters for the various class levels. The consistent occurence of a persistence ratio greater than unity at the senior level indicates that a large number of engineering students do not complete their undergraduate requirements in the normal four year period.

SECTION - 3 EQUIVALENT STUDENT PROFILES

The computer output for Section - 3 outlines a quarter by quarter profile of regular and limited student enrollment and a comparison with the full-time student equivalent. The full-time equivalent student is a calculational category utilized for budgeting and staffing purposes and assumes a 15 unit academic load for the student.

When evaluated on successive like quarters (Fall 1969, Fall 1970 etc.) the data reveals a steady decline in FTE over the years. This is further substantiated by the decline in average unit load of the students when compared on the same basis.

The engineering undergraduate curriculum at California State Polytechnic University, Pomona consists of 198 quarter units. Based on a normal academic year of three quarters, the average unit requirement for a normal progression to graduation in four years would be 16.5 units per quarter. Since the average unit load being taken by the student, as revealed by the data, is less than 15 units, the compaction at the senior class level and the high value of persistence ratio previously discussed in Section - 2 is understandable.

SECTION - 4 RATIO-TREND ANALYSIS

The purpose of Section - 4 is to provide the computer output data in a form that reveals trend developments. Monitoring the trends over successive periods provides a basis for decisions affecting the academic community.

Using the previous quarterly data, academic enrollment and class profiles and related ratios were developed on an academic year basis.

The academic year enrollment profile provides data on the total enrollment for the academic year and related ratios. It is noted that there is a continued increase in transfer student enrollment while first time freshman enrollment continues to decline. To compare the makeup of new student

enrollment a ratio of transfer students to the total of first time freshmen and transfer students was developed. This confirms the previous quarterly data trends although in a somewhat different form. Visual interpretations of the enrollment profile trends are provided.

Following somewhat the same theme as utilized in the enrollment profile, the academic year average class profile and their related ratios were developed. The ratios confirm the trends previously revealed by the quarterly data, in particular, the compaction at the senior class level. Visual displays are also provided.

The lower portion of the first tabular output of Section - 4 compares the new "incoming" enrollments with the "outgoing" graduates over the course of the total academic year. The related ratio, academic year growth profile ratio, is a measure of the trend of the growth or decline of a number of engineering students enrolled in the institution for that given year.

In this institution the fall quarter plays a prominent role in academic planning for budgets, staffing etc. Because major enrollments occur in this quarter and staffing needs are projected on meeting these peak demands, fall quarter enrollment and class profiles together with associated ratios were developed as an aid to academic planning.

UNIVERSITY TECHNICAL MANPOWER RESOURCES
SUB-SYSTEM

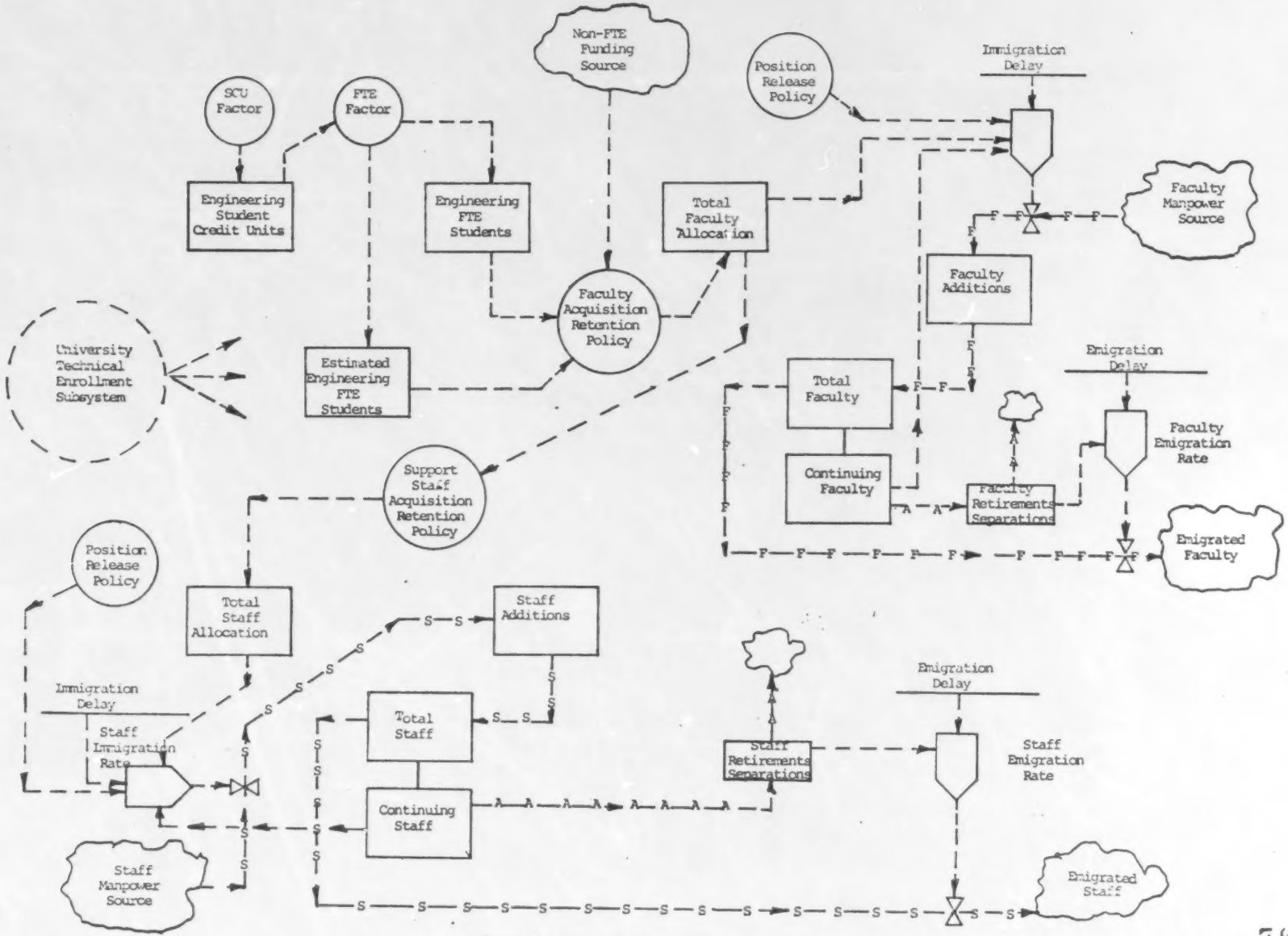


Figure 2. *"University Technical Manpower Resources Subsystem"*

UNIVERSITY TECHNICAL MANPOWER RESOURCES SUB-SYSTEM

The University Technical Manpower Resources Sub-System is depicted in Figure 2. The computer simulation output for this sub-system is designed in 7 basic sections. Output data is provided for the total School of Engineering and the individual departments.

Section - 1 Academic Program-Enrollment Data

Provides data on current quarter class offerings, enrollment and associated data.

Section - 2 Faculty/Staff Resources-Utilization

Summarizes the faculty and staff resources and their utilization for the individual departments.

Section - 3 Departmental Summary

Provides a summary of faculty and staff resources by rank, earned position fractions and earned weighted teaching units for comparison with the allocations in Section - 2.

Section - 4 Course Levels - Unit Profiles

Supplies data on the number of courses taught at each level by departments in the School of Engineering. The course data is divided in lecture, laboratory and project type. Additional data such as average class size, student faculty ratios, student credit units, full time equivalent students, and weighted teaching units are provided within these subdivisions.

Section - 5 School Summary

Provides a composite of faculty and staff resources by rank, earned position fractions and weighted teaching units for the total School of Engineering.

Section - 6 Ratio Analysis

Calculates the full time equivalent student generated by the number and type of course offerings. The cost in weighted teaching units to generate these full time equivalent students provides a basis for analysis of possible optimization of course offerings.

Section - 7 Trends Analysis

Is a summary by quarters, over a maximum of sixteen quarters, of student faculty ratios, faculty positions earned and budgeted, full time equivalent students and associated ratios for individual departments. A summary of this data for the total School of Engineering with three year averages provides a data base for estimating future staffing needs.

CONCLUSIONS

CONCLUSIONS

Preliminary system analysis may be accomplished in varying depths. In this study, a relationship between gross variables indicates interactions between the social, economic, political, ecological and technological forces. The generality of the variables preclude detailed and specific interactions. Thus, it is indicated that an expansion of the preliminary system analysis is required if specificity is desired. Estimates of the order of expansion required are approximately a factor of five.

System structure development which follows the preliminary system analysis, requires an expansion by a factor of ten based on conservative estimates. The effort required for an adequate systems dynamic model for academic planning is substantial and should not be underestimated. However, it would not be unreasonable to form academic planning research and forecasting groups within the engineering sectors of higher education to perform this task and provide the necessary support for their activities.

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APPENDIX A

EXPLORATORY AND NORMATIVE FORECASTING

APPENDIX A

EXPLORATORY AND NORMATIVE FORECASTING

Introduction

Exploratory technological forecasting includes a variety of techniques for predicting the future state of science and technology. Unfortunately, most of the methods are really only variants on simple trend extrapolation procedures, broadly defined, that have limited utility in today's rapidly shifting technological environment. The principal exploratory methods are:

(1) so called "genius" forecasting based either on individual wisdom or on a group "genius" forecasting process known as the Delphi technique, and

(2) formal trend extrapolation to either a straight-line fit or an S-shaped expectation.

The formal trend methods include single-curve projections as well as estimations based on the envelope encompassed by the projection of a family of related curves. They also include both the extrapolation of a single time series as well as the projection of lead-lag relationships between two time series, the latter known as "precursive event" forecasting.

Intuitive Trend Forecasts

In theory, technological forecasting is not supposed to be able to foretell the "major breakthrough." In fact, this is one of the few ways in which intuitive hunches or guesses might provide service. Occasionally, but unpredictably, the brilliant scientist (or the perceptive marketeer, or the starry-eyed science fiction writer) may predict the future as different from a mere

extension of the past. But more usually individual wisdom-based forecasting works on the rule that "past is prologue." Trend extrapolation thus becomes the simple kind of model that the unaided mind can manipulate intuitively.

With the promotional boost of The RAND Corporation's sponsorship, the hunches of individual "experts" have been coaxed and guided in an iterative group forecasting procedure known as the "Delphi method." This Delphic oracle procedure assumes that collective (and normalized) wisdom is better than individual "guesstimates," although recent behavioral research plus the mythology regarding Delphi itself question this assumption. In using the Delphi approach a panel of experts is solicited for their opinions on the future technology in a specified area. Assembled opinions thus gathered are redistributed to the panel for a series of reassessments during which criticisms and defenses of extreme forecasts are also obtained and communicated. The end result tends to be a more polarized and justified range of future estimates than were originally gathered. Thus the collective "ballpark guesses" of the experts are refined and legitimized. It is interesting to speculate whether a Delphi sampling of the appropriate whiz kids would have predicted an effective intercontinental ballistic missile when Vannevar Bush failed in his prophecy! Would Delphi have done better than Lindemann in his lack of foreseeing the German V-2 rockets? Is there sufficient evidence to believe that the Delphic search for concensus produces more "truthful" forecasts than a comparable assemblage of individual genius forecasts?

Formal Trend Forecasts

Those who lack the wisdom demanded by genius forecasting (perhaps in reality they possess the wisdom needed to appreciate the weaknesses of the intuitive methods!) have adopted formal procedures for translating the events of the past into the predictions of the future. Data on the time-history of some parameter of technological progress (e.g. tensile strength of materials, engine thrust per lb. of fuel) are plotted against time on linear or logarithmic scales. Using "eyeball" extrapolation, or statistical "best fit" procedures, a growth-of-technology line is drawn through the data points and extended into the future. An assumption of technology saturation effects produces the biological growth pattern with its S-shaped curves; an assumption of no saturation leads merely to longer straight lines. Poor fit of the data to a single line suggests the need for alternative technological projections, and often leads to a forecast of an envelope of possible technological states. When two sets of these progress parameter curves appear to be correlated, with one curve consistently leading the other in time (e.g., the speed of bombers versus commercial transports), similar trend extrapolations are applied. In this case, the process is referred to as forecasting by the analysis of precursive events.

The trend extrapolations, both intuitive and formal, fail to state explicitly their underlying assumptions. As Jantsch points out, ". . .the simple extrapolation of secular trends does contain one analytical element--the intuitive expectation that the combined effect of internal and external factors which

produced a trend over a past period will remain the same during a future period, or that it will undergo an estimated gradual change." Yet the changes occuring in numerous areas of technology deny the validity of these stability-oriented assumptions.

An Appraisal of Normative Technological Forecasting

Noramtive technological forecasting activities attempt to provide a basis for allocating technology generating resources so as to maximize attainment of organizational goals. The effectiveness of any normative method depends upon:

(1) the meaningfulness of its treatment of goals;

(2) the correctness of its assumed relationships between allocated resources and generated technology;

(3) the adequacy of its balancing of the resources-to-technology considerations against the worth of goal fulfillment; and

(4) the implementability of the method, including the ability to acquire reasonable costs as well as the ability to persuade organizational decision-makers to use the generated outputs.

Most of the effort in the development of normative forecasting techniques has gone into items 1 and 3 above. The expression of goals, the establishment of values for them, the accounting for the conflicting interests of various groups, are primary questions debated by the designers of normative forecasting methods. The techniques for manipulating the resources being allocated against these assumed values are also many and varied, ranging from simple linear and dynamic programming to elaborate embodiments of Bayesian analyses and Monte Carlo techniques. And these techniques are under continuing refinement with accompanying developments of the computer software needed for the desired calcu-

lations. These areas can be left to others to criticize.

Yet items 2 and 4 above have been largely ignored. Little effort has been devoted to making the forecasting techniques practicable or believable by the manager. The most sophisticated, perhaps even the best, normative approach requires thousands of estimate inputs for every use. Moreover, the assumed relationships between allocated resources and generated technological outputs are seldom even explicitly identified in the normative techniques. Usually, the forecasts receive as inputs the estimates of the technical outputs that would be produced by various funding levels. In other words, in most cases no exploratory forecasting technique is used to generate the basis for normative manipulations! The assumed technical outputs are guesses only.

Integrating Exploratory and Normative Forecasting
With Dynamic System Models

Throughout this paper, the inconsistencies between the developments of exploratory and normative forecasting techniques have been highlighted. In mathematical sophistication and level of detail the simple schemes used by those trying to predict technology of the future look pallid when matched against the techniques employed by those who are allocating the resources that will create the future. The examination of exploratory forecast methods indicates that what is known about the process that generates future technology is not presently included in the forecasting models. This lack shows up further as a critical weakness of the normative techniques, which are attempting to select and budget R&D projects based on meager schemes for forecasting future technological possibilities.

An earlier section of the paper pointed out the potential of dynamic models which are oriented toward the inclusion of those cause-and-effect relationships

that are likely to alter future technological developments. These models are being utilized in economic analysis, forecasting and policy design, i.e., in both exploratory and normative modes. Jantsch has realized how much these dynamic system models might contribute to technological forecasting. However, he has seriously underestimated the degree of their present development.

Rigid computer models are on the threshold of becoming useful for technological forecasting. In particular, "dynamic forecasting" is serving as a guideline in a number of serious attempts; this term, introduced by Lenz to denote the modelling of all significant cause-effect relationships which influence the growth of technology in general or a functional capability, may be extended here so as to include technology transfer in general. The hope of course, is to achieve adequate results with a limited dynamic model. The "Industrial Dynamics" concept of Forrester for complex business decision-making provides the background to many attempts in this area.

The "Industrial Dynamics" concept that Jantsch references emphasized the importance of feedback relationships in influencing the dynamic evolution of a situation. For example, the connections between exploratory and normative forecasting form the kind of feedback loops that significantly affect future behavior. An exploratory forecast generates a prediction that a desired outcome is highly feasible within a reasonable time period; this leads to a high value index established for the related R&D project in the normalized forecast, which in turn influences increased funding for the project. The resultant strengthened research support enhances the likelihood of timely completion of the project, and this status imporvement is reflected in the exploratory forecast. This type of feedback relationship is critical to the technological growth process and it demands the integration of the exploratory

and normative phases. Dynamic feedback system models are the most likely candidates for accomplishing this integration.

APPENDIX B

UNIVERSITY TECHNICAL ENROLLMENT SUB-SYSTEM

DATA

Program listing and data output can be provided on request.

APPENDIX C

UNIVERSITY TECHNICAL MANPOWER RESOURCES SUB-SYSTEM

DATA

Program listing and data output can be provided on request.